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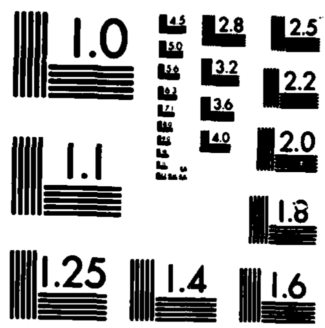

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User's Guide to Calibration of Pneumatic Controllers in Heating, Ventilating, and Air Conditioning (HVAC) Systems

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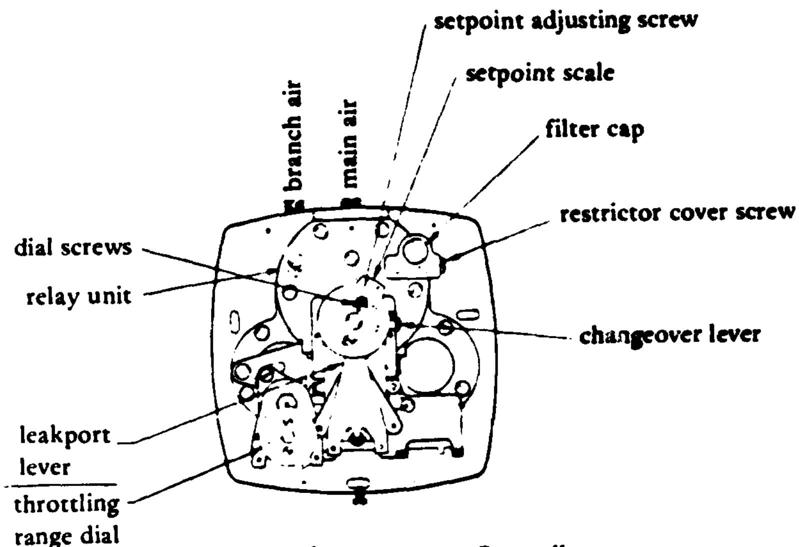
DEFINITIONS

The calibration of proportional pneumatic controllers (Figures 1 and 2) requires knowledge of at least three things: the controller action, the setpoint, and the throttling range.

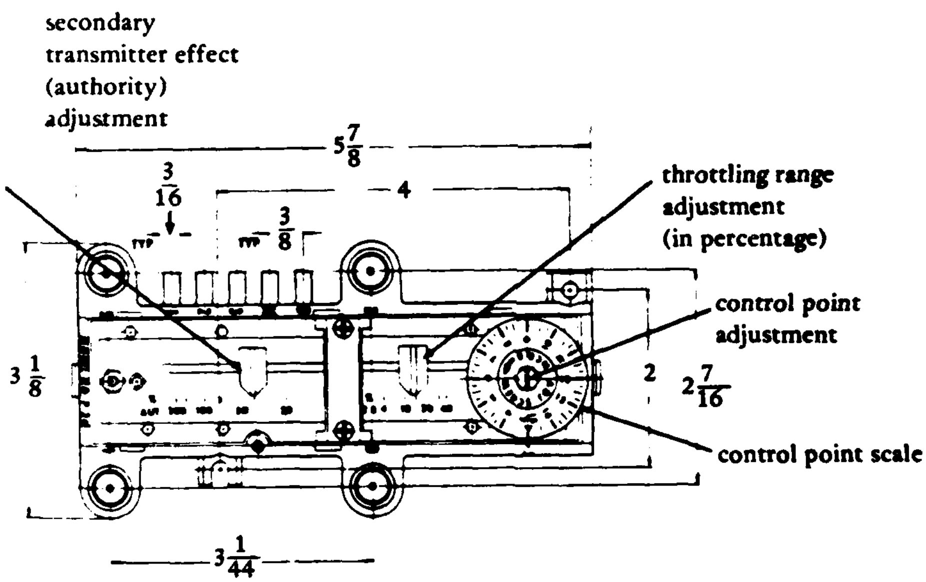
Action. A controller is either direct acting or reverse acting. In a direct acting controller, an increase in the input pressure to the controller results in an increase in the output pressure from the controller. In a reverse acting controller, an increase in the input pressure results in a decrease in output pressure.

Setpoint. The value to which the control point setting mechanism is set. For example, a temperature controller might be set at 75°F.

Throttling range. The change in the input variable required to produce the maximum change in the output variable. For example, if a change of 4°F at the input sensor of a single input temperature controller results in the full range of controller output pressure, the throttling range is 4°F. See Figure 3.



Typical Temperature Controller



T.R. in P.S.I.	.5	1.2	1.87	2.5	3.75	5.0
T.R. in %	4	10	15	20	30	40

Receiver Controller

Figure 1. Typical single and two input pneumatic controllers.

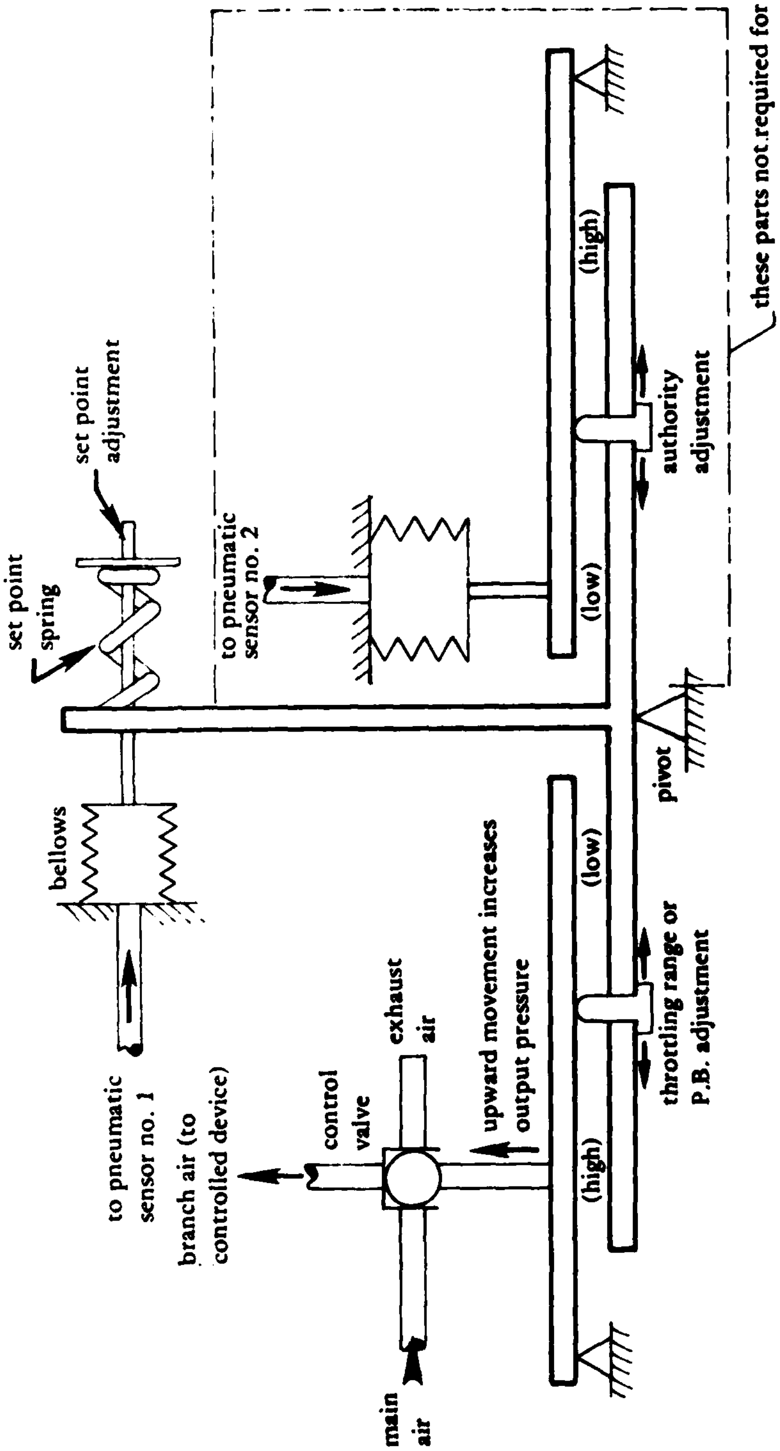


Figure 2. Typical pneumatic controller mechanism.

Other definitions often used by controller manufacturers are:

Proportional band. The throttling range of a controller divided by the span of its sensor, expressed as a percentage.

$$\text{Proportional Band} = \frac{\text{Throttling range} \times 100}{\text{Span}} \qquad (1)$$

Sensor span is the design operating range of a sensor. See Figure 4.

Percent authority. The amount of influence a second controller input has on the output as compared to the influence of the primary controller input, expressed as a percentage.

$$\%\ \text{AUTH} = \frac{\text{Proportional band of primary input}}{\text{Proportional band of secondary input}} \times 100$$

$$= \frac{\text{Controller (1) throttling range}}{\text{Controller (2) throttling range}}$$

$$\times \frac{\text{Sensor (2) span}}{\text{Sensor (1) span}} \times 100 \qquad (2)$$

For example, if the percent authority equals 100%, the second sensor has the same influence on the magnitude of the controller output as the primary sensor; if percent authority equals 10%, the second sensor has only one-tenth the influence as the first. Percent authority is applicable only to two input, or reset, controllers. A typical pneumatic controller is designed to permit the percent authority to be adjusted to a value between 10% and 200%.

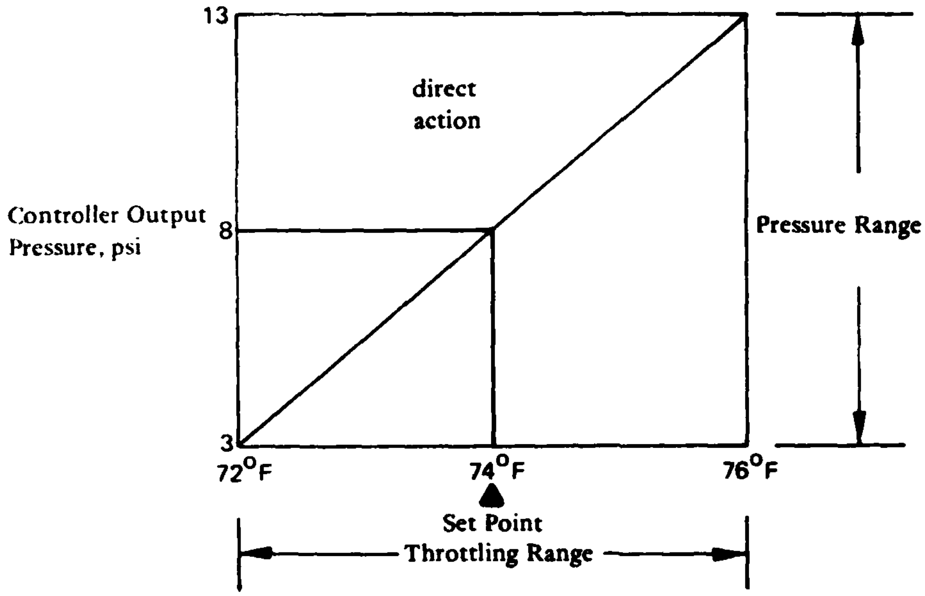


Figure 3. Illustration on controller nomenclature.

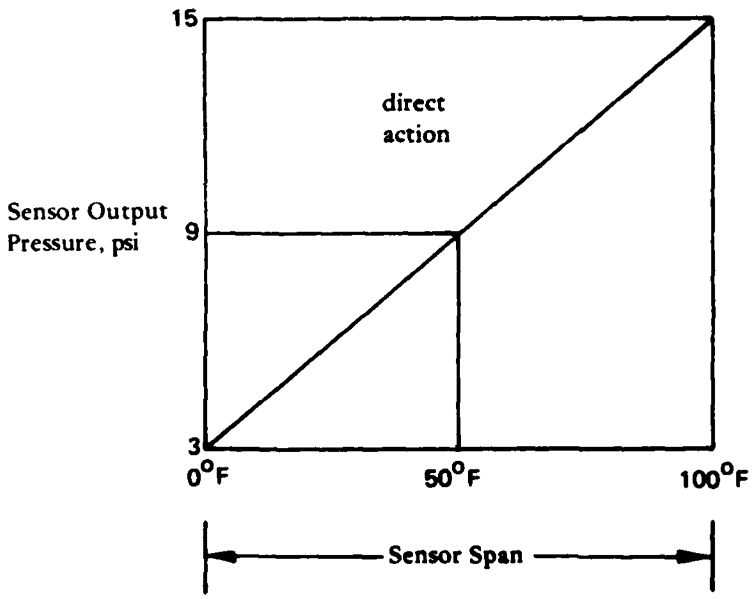


Figure 4. Illustration of sensor nomenclature.

Range. The operating range of a sensor as specified in a reset schedule. Applicable only to two input controllers.

Sensitivity. Sensitivity is the change in output pressure of a sensor (or transmitter) divided by the change in the measured variable. For example, if the output of a sensor varies from 3 to 15 psi for a change in temperature of 100°F, the sensitivity is

$$\text{Sensitivity} = \frac{12 \text{ psi}}{100^\circ\text{F}} = 0.12 \text{ psi}/^\circ\text{F}$$

Gain. Gain is the ratio of output pressure of a receiver or controller to the input pressure. If a 1-psi input signal results in a 10-psi output, the gain equals 10. A useful relationship is:

$$\text{Gain} \times \text{Sensitivity} \times \text{Throttling range} = 1$$

Ratio. Ratio is defined as:

$$\text{RATIO} = \frac{\text{Sensitivity of primary sensor} \times TR_1}{\text{Sensitivity of secondary sensor} \times TR_2} \qquad (3)$$

GENERAL PROCEDURE

The calibration procedure presented below can, in principle, be applied to any pneumatic single- or dual-input controller or pneumatic transmitter-receiver/controller combination.

The calibration procedure follows these steps:

(1) Measure controller input(s)
(2) Predict controller output
(3) Measure controller output
(4) Adjust controller as required

The controller is calibrated at the control point, or actual condition, rather than the setpoint, which is an idealized, desirable condition. This choice of method and calibration point means that only those controllers which are out of calibration need to be adjusted. Controllers that are in calibration need not have any settings or adjustments altered. If a controller cannot be calibrated or will not remain calibrated for a reasonable period of time, it is defective and should be repaired or replaced.

Single-Input Controllers

First, determine the desired action, setpoint, and throttling range (or proportional band) for the controller from the control system plans or specifications. Remove the cover and examine the settings on the controller mechanism. Verify action and throttling range settings. Next, measure the controlled variable: zone temperature or humidity for example. Do not rely on the installed pneumatic sensors and gauges for this measurement. Use a calibrated, independent instrument. Then apply these data to the following equation:

$$\begin{matrix}\text{Predicted}\\ \text{Output}\\ \text{Pressure}\end{matrix} = \left[\frac{\text{Mid-Point}}{\text{Pressure}}\right] \pm \left[\frac{V - SP}{TR}\right] \times \left[\frac{\text{Pressure}}{\text{Range}}\right] \quad (4)$$

where:	Mid-Point pressure	=	pressure at middle of controller operating range. Usually 8 psi (see Figure 3)
	+	=	for direct action controller
	-	=	for reverse action controller
	V	=	measured variable, °F, % RH, psi
	SP	=	controller set point, °F, % RH, psi
	TR	=	controller throttling range, °F, % RH, psi
	Pressure Range	=	range of controller operating pressure, usually 13 psi - 3 psi = 10 psi

Next, measure the actual pressure in the controller output line. Some controllers have test ports to facilitate this, while others must have the output temporarily disconnected from the controlled device and connected to a test gauge. Pneumatic systems connected with plastic tubing can have line pressures measured by means of a pressure gauge connected to a small hollow needle. Follow the control manufacturer's recommendations for measuring the pressures in their devices. Use an accurate, calibrated pressure gauge.

Compare the output pressure predicted by Equation 4 to the measured output pressure. If the two values are within 10% of each other, the controller can be assumed to be calibrated. If the two values differ by more than about 10%, the controller should be recalibrated.

Example. A direct acting proportional controller used to control supply air temperature in an HVAC system is specified to be direct acting and to have a setpoint of 74°F and a throttling range of 4°F. The measured supply air temperature is 75°F. The predicted controller output pressure is therefore (from Equation 4):

$$P_{OUT} = \left[8 \text{ psi}\right] + \left[\frac{75 - 74}{4}\right] \times \left[13 - 3\right] = 10.5 \text{ psi}$$

The measured output pressure = 11 psi. The

$$\text{Percent Difference} = \left[\frac{11 - 10.5}{10.5}\right] \times 100 = 4.8\%$$

so the controller is reasonably close to being in calibration.

If the measured output pressure equaled 9.5 psi, then

$$\text{Percent Difference} = \left[\frac{10.5 - 9.5}{10.5}\right] \times 100 = 9.5\%$$

and the controller should be calibrated.

Calibration Procedure for Single-Input Controllers

First, make sure the main air supply is at the design pressure, usually 17 to 20 psi. If the main air pressure is not as specified at the device being calibrated, check for excessive air leakage, crimped tubing, dirty filters, a faulty or incorrectly set pressure regulator and other causes of incorrect main air supply pressure.

A single-input pneumatic controller is calibrated using either of the following procedures:

Procedure A

(1) Loosen the setpoint scale so that it can rotate freely.

(2) Install calibrated pneumatic gauge in the output (or branch) line.

(3) Turn the setpoint adjustment screw until the controller output pressure is equal to the value predicted by Equation 1.

(4) Rotate the setpoint scale until the indicated value equals the desired setpoint.

(5) Tighten the setpoint scale.

(6) After system comes to equilibrium, compare predicted and measured values of output. Repeat steps 1 through 5 if necessary.

Procedure B

(1) Disconnect the sensor (or input) line from the controller.

(2) Connect a calibrated pneumatic gauge to the input port of the controller with a "T" connection (see Figure 5).

(3) Connect an adjustable restriction, such as a needle valve, to the "T" connection.

(4) Connect the free end of the adjustable restriction to the main air supply

(5) Connect a calibrated pneumatic gauge to the output port of the controller.

(6) Adjust the restriction until the input pressure gauge reads the value of the pressure corresponding to the desired setpoint. You will need data on sensor span and pressure range for this step.

(7) Turn the setpoint adjustment screw until the output pressure equals the mid-point pressure value (typically 8 psi).

(8) Adjust the setpoint scale to read the selected value of setpoint.

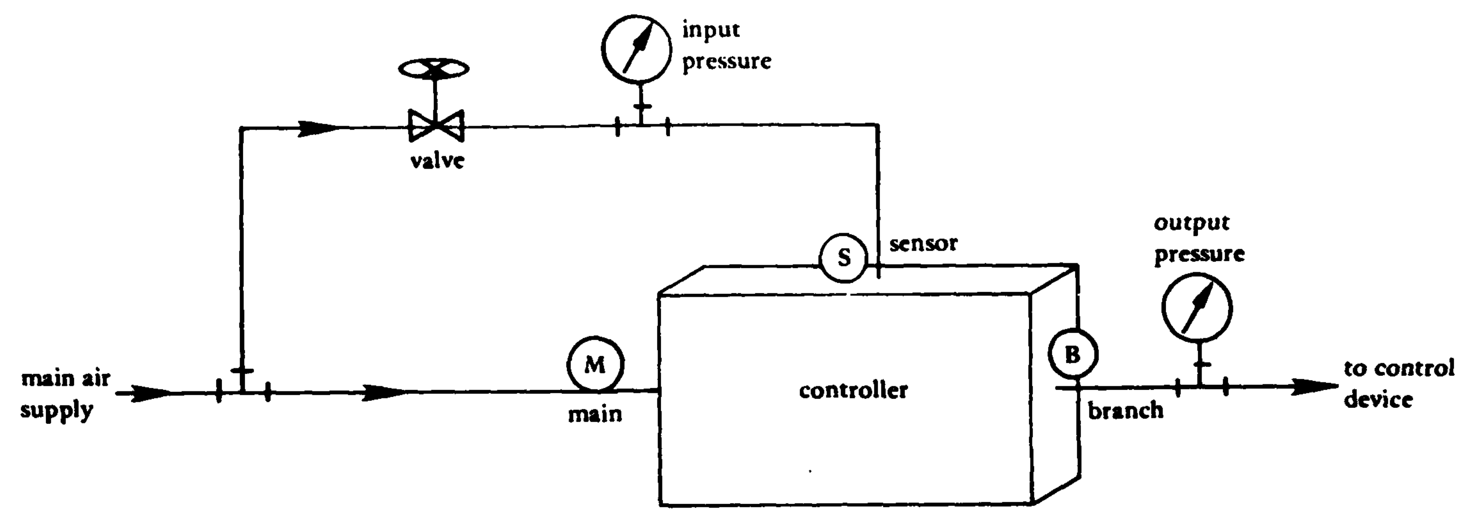


Figure 5. Illustration of test apparatus.

Dual-Input Controllers

The calibration procedure for two-input controllers is slightly more complicated because the setpoint of the controller is automatically changed or "reset" by the second input to the controller. For example, a two input controller would be used to change, or reset, the temperature of the water supplied to a hot water heating coil based on a relationship between desired hot water temperature and outdoor air temperature. This relation between the variable measured by the first sensor and the variable measured by the second sensor is called a "reset schedule." Knowledge of the specified reset schedule for a controller is required to calibrate a two-input controller.

Reference to Figure 2 shows that a portion of the input force from the reset sensor is added directly to the input force from the primary sensor. This is typical of pneumatic controller design. The amount of influence the second sensor has on the value of controller output pressure is regulated by means of the AUTHORITY setting. For the controller illustrated in Figure 2, the equation describing the output pressure is

$$\text{Predicted Output Pressure} = (\text{Mid-Point Pressure}) + \left(\frac{V_1 + \frac{\%\,\text{AUTH}}{100} \times V_2 - SP}{TR} \right) \times (\text{Pressure Range}) \quad (5)$$

Equation 5 is for direct action sensors (i.e., sensor output pressure increases with an increase in the sensed variable). The branch line pressure of the controller will increase with an increase in either the primary variable (V_1) or the reset variable (V_2). Thus, the controller described above can be said to have direct/direct action. The action of controllers can be changed by using one or more reverse action sensors and, in some controller designs, by moving the positions of the controller linkages and pivot points. Confusion and errors are minimized, however, if only direct action sensors are used in an HVAC control system and all controller actions are of the same type (e.g., direct/direct). If reverse controller action is required it is best obtained by connecting a reversing relay between the controller and the controlled device.

Example. A two-input pneumatic proportional controller is used to reset, or change the temperature setpoint, of a hot water supply based on the temperature of the outdoor air as illustrated in Figure 6. Reset is employed to reduce energy consumption and short-cycling of mechanical equipment. The reset schedule is presented in Figure 7. This application illustrates reverse reset action since a decrease in the value of the reset variable (T_{OA}) has the same effect as raising the setpoint on a single-input controller measuring the primary variable (T_{HWS}). In general, direct/direct action two-input controllers produce reverse reset action. It is helpful to put the reset schedule information in tabular form:

State	S_1 (°F)	S_2 (°F)	BLP (psi)	Valve	Condition
A	200	20	3	open	100% through boiler
B	120	70	13	closed	100% boiler bypass

Equation 5 must be satisfied at all points on the reset schedule. In particular, it must be satisfied at the end points. This knowledge permits calculation of the effective setpoint and authority setting from the data defining the reset schedule. Simultaneous solution of Equation 5 at the extreme points of the reset schedule (see Figure 7 for nomenclature) yields the following relationship for percent authority:

$$\%\ \mathrm{AUTH} = \frac{100\left(\frac{P_B - P_A}{\Delta P}\right)(TR) - 100(V_{1B} - V_{1A})}{V_{2B} - V_{2A}} \qquad (6)$$

The relationship for effective setpoint is

$$SP = V_{1B} + \left(\frac{\%\ \mathrm{AUTH} \times V_{2B}}{100}\right) - \frac{(P_B - P_{MID})}{\Delta P} \times TR \qquad (7)$$

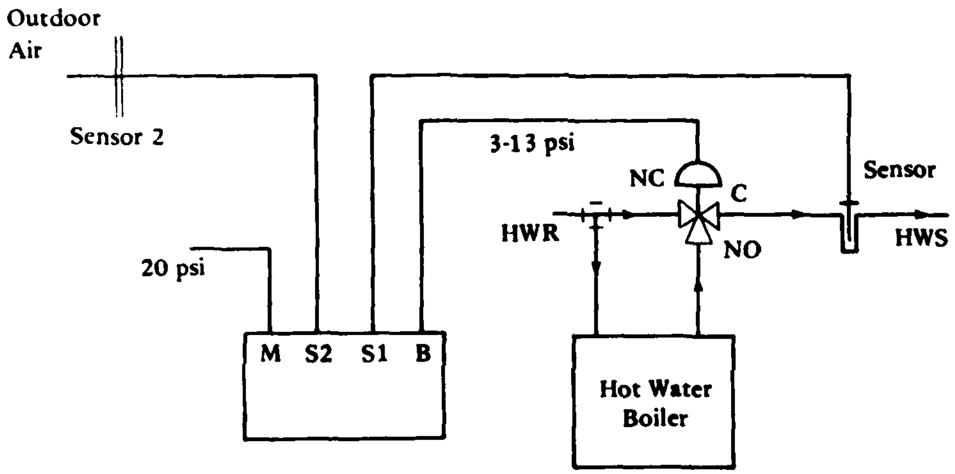


Figure 6. Application of Two-Input Controller.

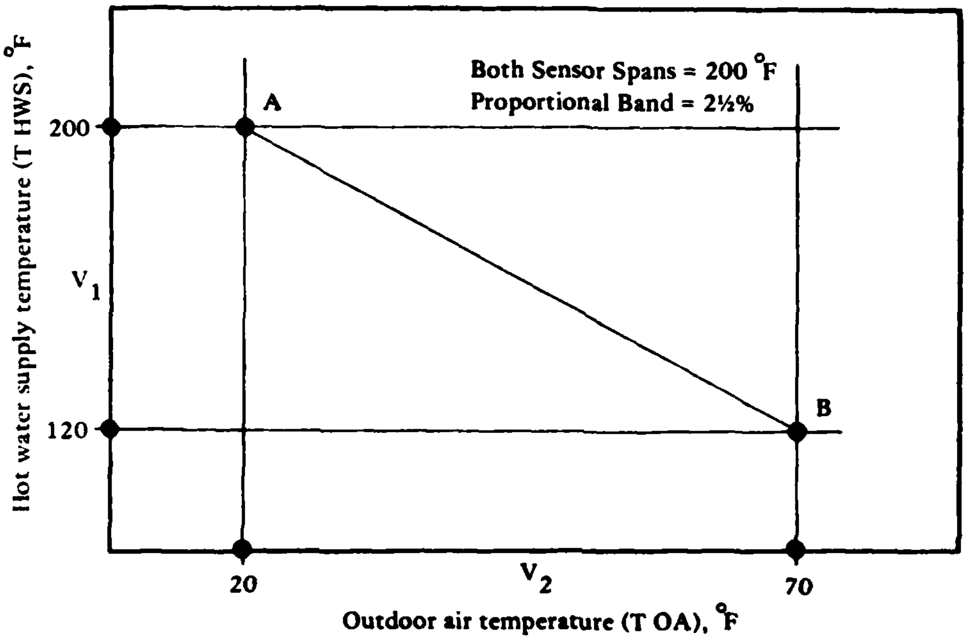


Figure 7. Reset Schedule.

In this example, the throttling range of the controller is

$$TR = \frac{PB \times SPAN}{100} = \frac{2.5 \times 200}{100} = 5°F \qquad (8)$$

The percent authority equals

$$\%\ AUTH = \frac{100\left(\frac{13 - 3}{10}\right)(5) - 100(120 - 200)}{70 - 20} = 170$$

The effective setpoint equals

$$SP = 120 + \frac{170}{100}(70) - \frac{(13 - 8)}{10}(5) = 236.5°F$$

Unfortunately, the calculated value of setpoint lies outside the range of adjustment of most controllers. There are three possible solutions to this problem: (1) reverse the primary and secondary sensor connections at the controller, (2) change the proportional band setting, or (3) change the reset schedule.

First, try interchanging the sensor designated the primary sensor and the sensor designated the secondary or reset sensor. If the sensor connections are switched at the controller, the values of % AUTH and SP become:

$$\%\ AUTH = \frac{100\left(\frac{13 - 3}{10}\right)(5) - 100(70 - 20)}{120 - 200} = 56.25$$

and

$$SP = 70 + \frac{56.25}{100}(120) - \frac{(13 - 8)}{10}(5) = 135°F$$

These values lie within the range of adjustment of most controllers. Thus,

Predicted Output Pressure =

$$8 \text{ psi} + \frac{T_{OA} + \frac{56.25}{100}(T_{HWS}) - 135}{5°F} \times 10 \text{ psi}$$

If the measured hot water temperature equals 185°F and the measured outdoor air temperature equals 30°F, the output pressure from the controller should equal

$$P = 8 + \frac{30 + \frac{56.25}{100} \times 185 - 135}{5}$$

$$\times 10 = 6.13 \text{ psi}$$

If the measured output pressure of the controller is within 10% of the predicted value, the controller can be considered to be calibrated. In this example, the output pressure should be between 5.5 and 6.7 psi.

Calibration Procedure for Dual-Input Controllers

The calibration procedure is as follows:

(1) Disconnect both the primary and secondary sensors from the controller and install calibrated pressure gauges and adjustable restrictions in their place following the example of Figure 5.

(2) Connect the open ends of the adjustable restrictions to the main air supply.

(3) Connect a calibrated gauge to the output port.

(4) Select one end of the range of primary sensor, say V_{1A}, and adjust the restriction until the gauge on the primary sensor port reads the value of V_{1A}.

(5) Adjust the restriction on the second sensor port until the gauge for the secondary sensor reads the value of V_{2A}.

(6) Check to see that the settings for authority and proportional band are as specified. Adjust these values to specification if necessary.

(7) Turn the setpoint adjustment screw until the output pressure is at the desired extreme value (e.g., 3 or 13 psi).

(8) Adjust the setpoint scale to read the calculated value of setpoint.

(9) Adjust the restrictions on the sensor ports so that the input gauges read the values of V_{1B} and V_{2B}. The output pressure should now read the other extreme value (e.g., 13 or 3 psi).

(10) After the HVAC system returns to equilibrium, recheck the calibration.

Any controller that cannot be calibrated or does not stay in calibration should be repaired or replaced. Controller calibration checks should be performed at about 6-month intervals.

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